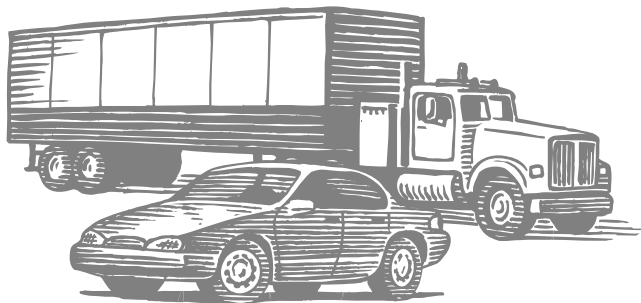


# Plug-in Hybrid Electric Vehicle Energy Storage System Design

*Advanced Automotive Battery Conference*

**Tony Markel and Andrew Simpson**  
**National Renewable Energy Laboratory**

May 19<sup>th</sup>, 2006

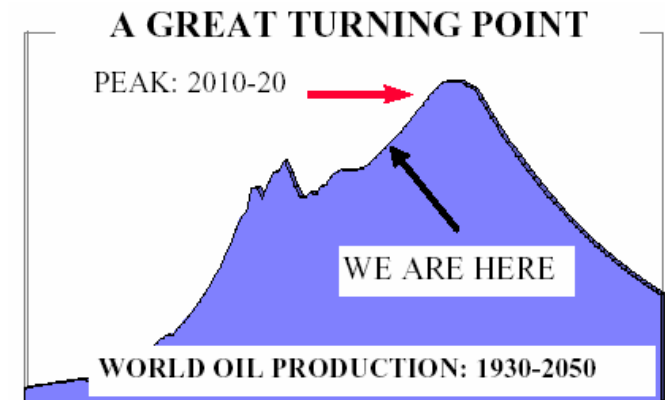
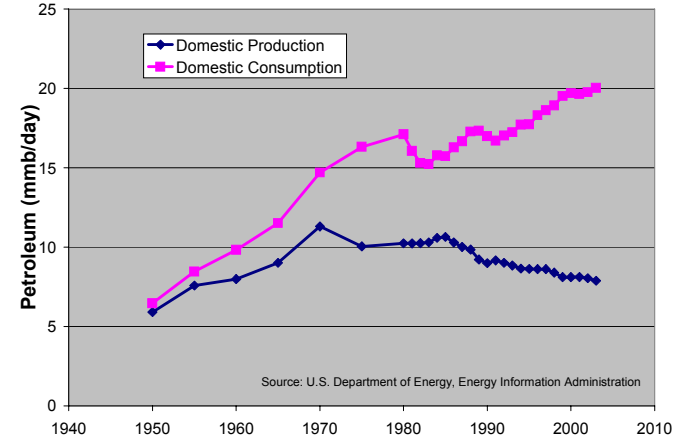
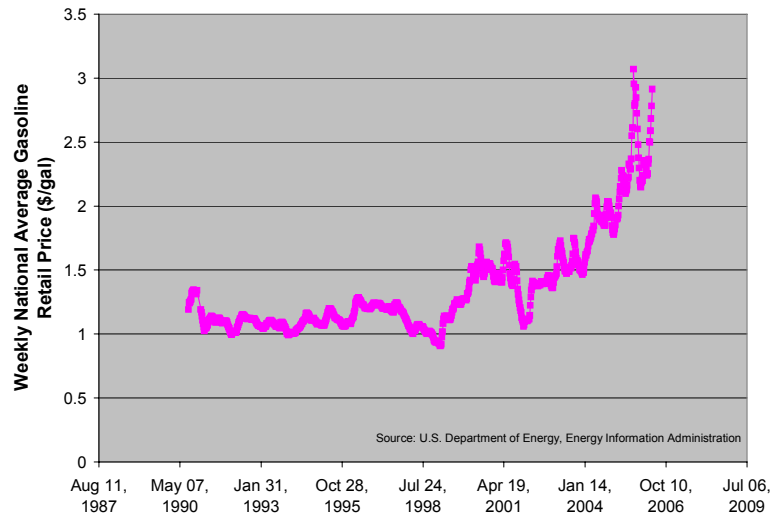


With support from the  
U.S. Department of Energy  
Office of Energy Efficiency and Renewable Energy  
FreedomCAR and Vehicle Technologies Program

# The Perfect Storm

- Petroleum **consumption** has steadily **increased** while domestic **production** has continued to **decline**
- World oil **production** predicted to **peak** within the next 5-15 years
- Recent increase in **gasoline price** is indicator of **growing tension** between supply and demand

Gasoline price - 85% rise in 5 years!

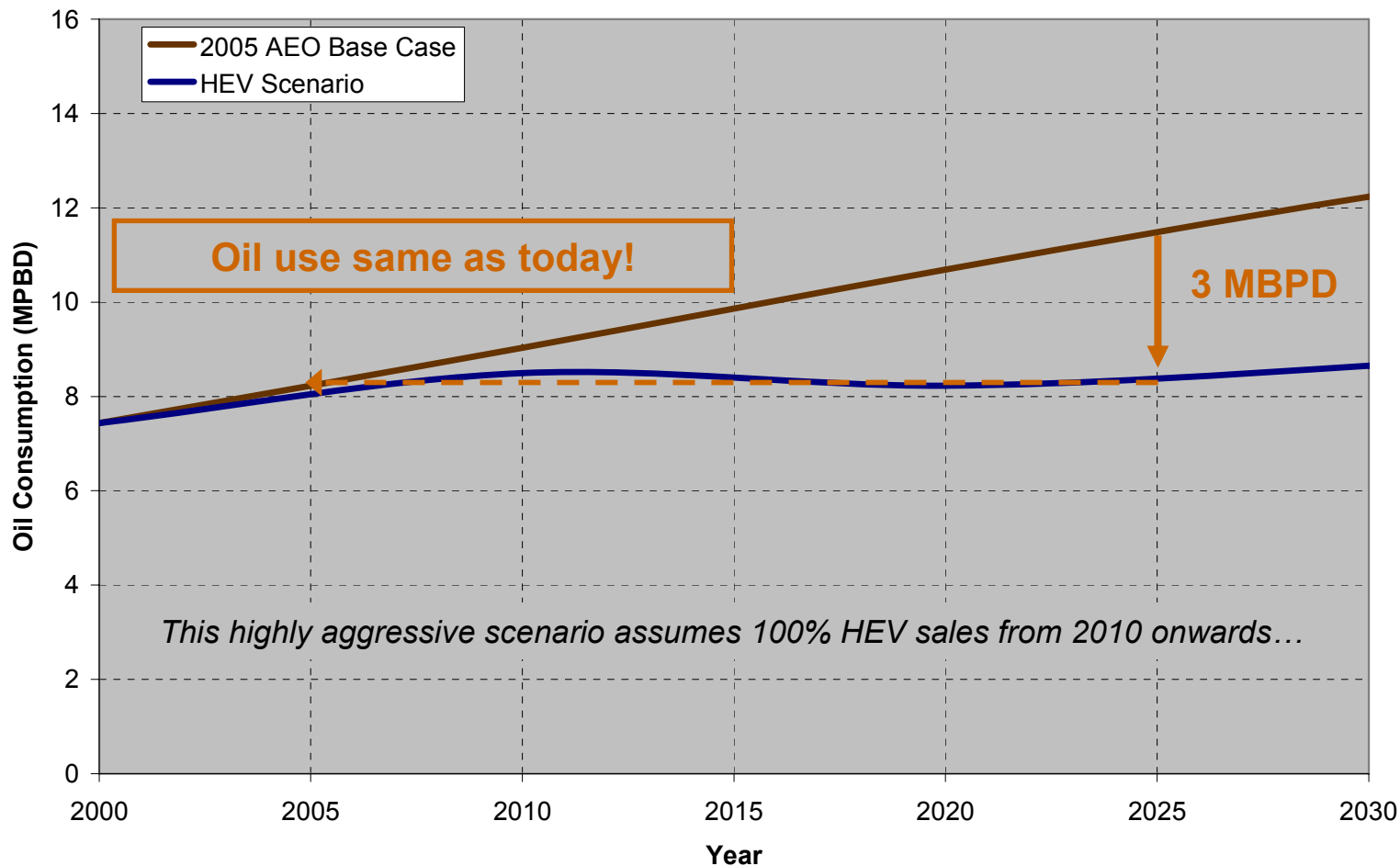


Source: Hubbert Center Newsletter #99/1 R. Udall and S. Andrews

## WHAT'S OUR PLAN?

# Oil Use Reduction with HEVs

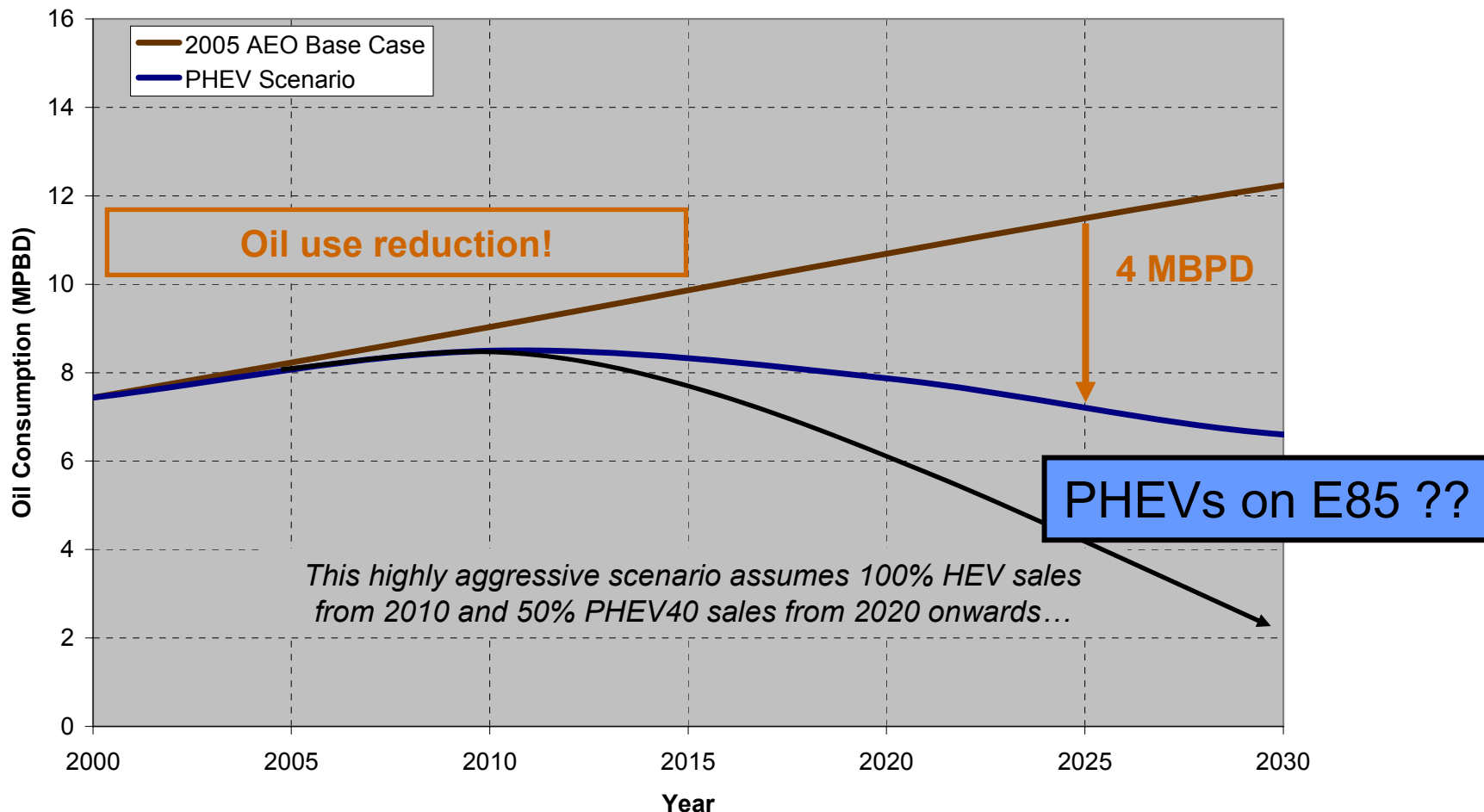
Light Duty Fleet Oil Use - Impact of HEVs on Consumption



HEVs unable to reduce consumption below today's consumption level

# Oil Use Reduction with PHEVs

Light Duty Fleet Oil Use - Impact of PHEVs on Consumption



PHEVs reduce oil consumption with a transition to electricity

# Recent PHEV Prototypes



EnergyCS Plug-In Prius



HyMotion Escape PHEV



DaimlerChrysler  
Sprinter PHEV



Renault Kangoo  
Elect'road



AC Propulsion  
Jetta PHEV



Esoro AG H301



AFS Trinity  
Extreme Hybrid™

# PHEV Batteries



Johnson Controls / SAFT



Cobasys

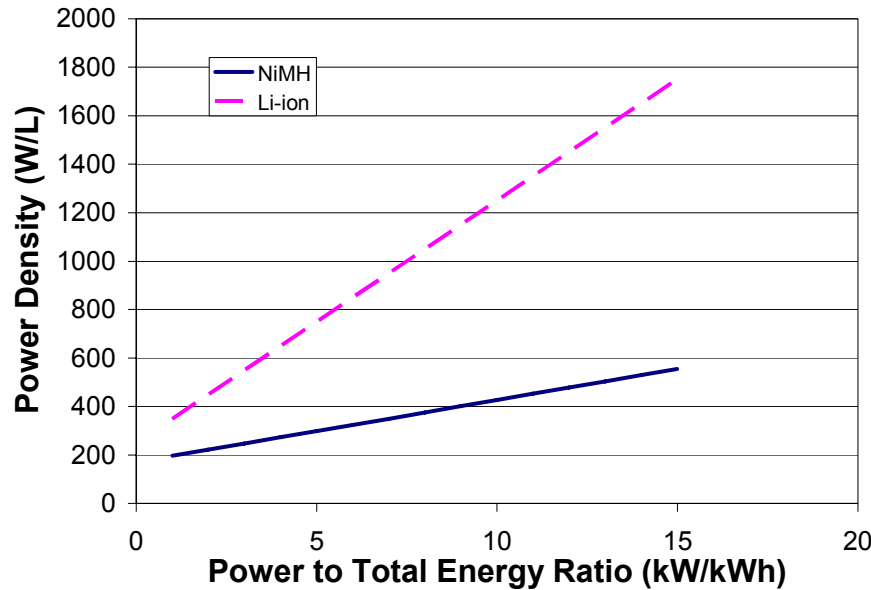


Valence Technologies

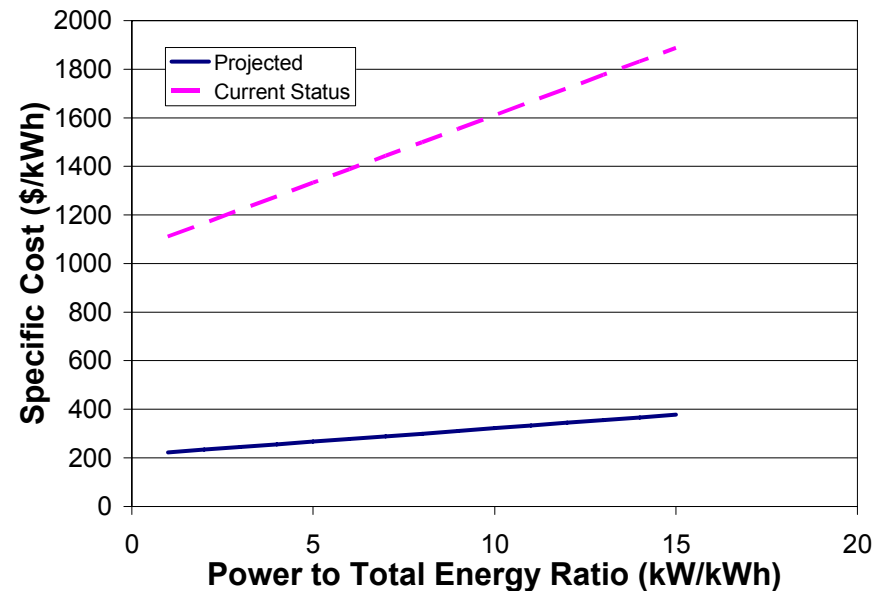
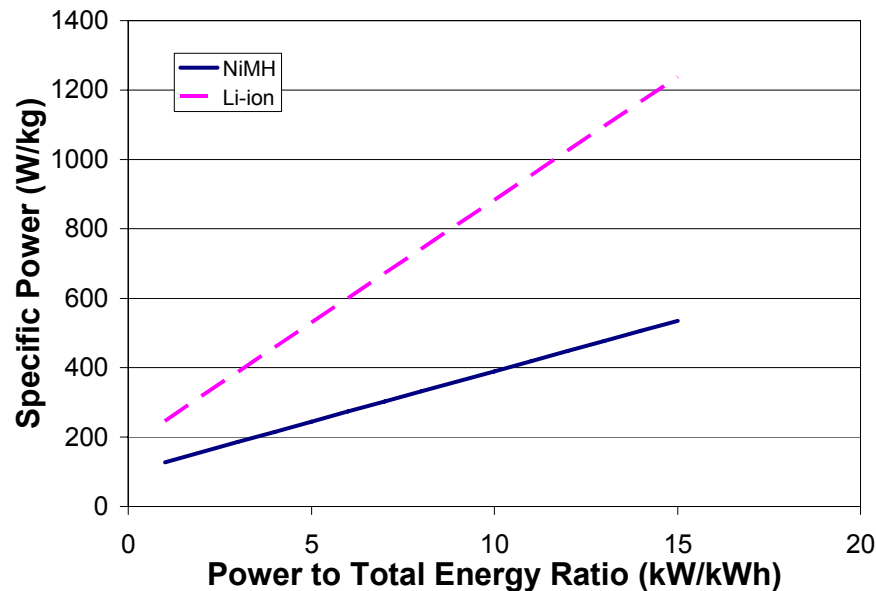


Hymotion

# Battery Characteristics

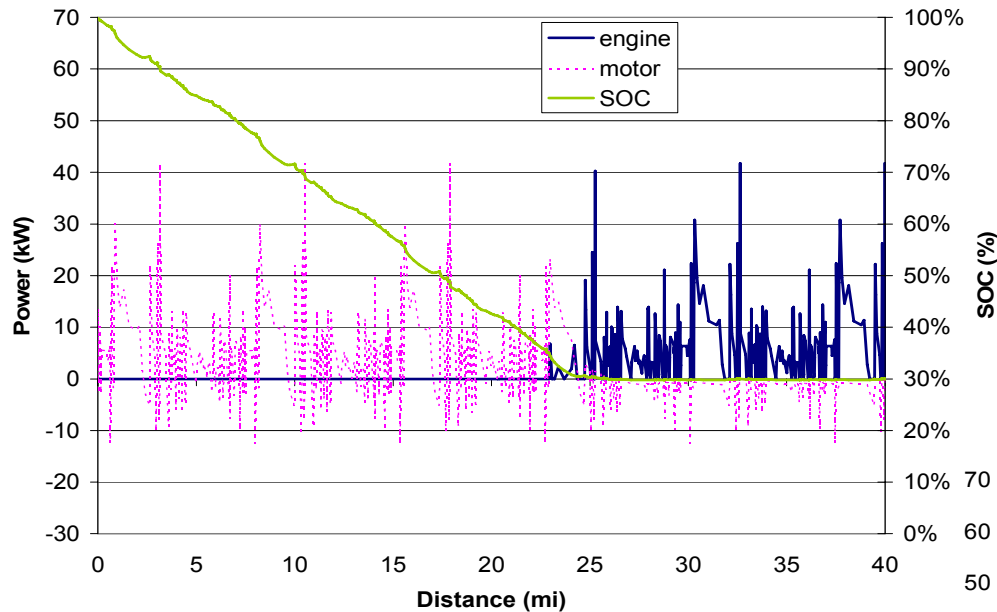


Lower power to energy ratio leads to lighter, smaller, and less expensive energy storage system



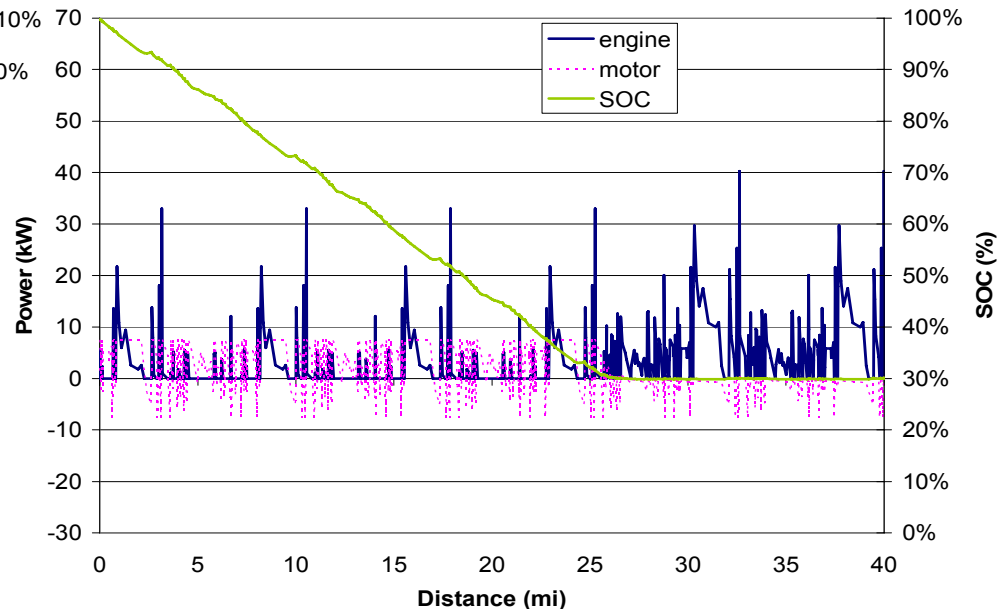
# All-Electric vs Blended Strategy

## All-Electric



- Engine turns on when battery reaches low state of charge
- Requires high power battery and motor

## Blended

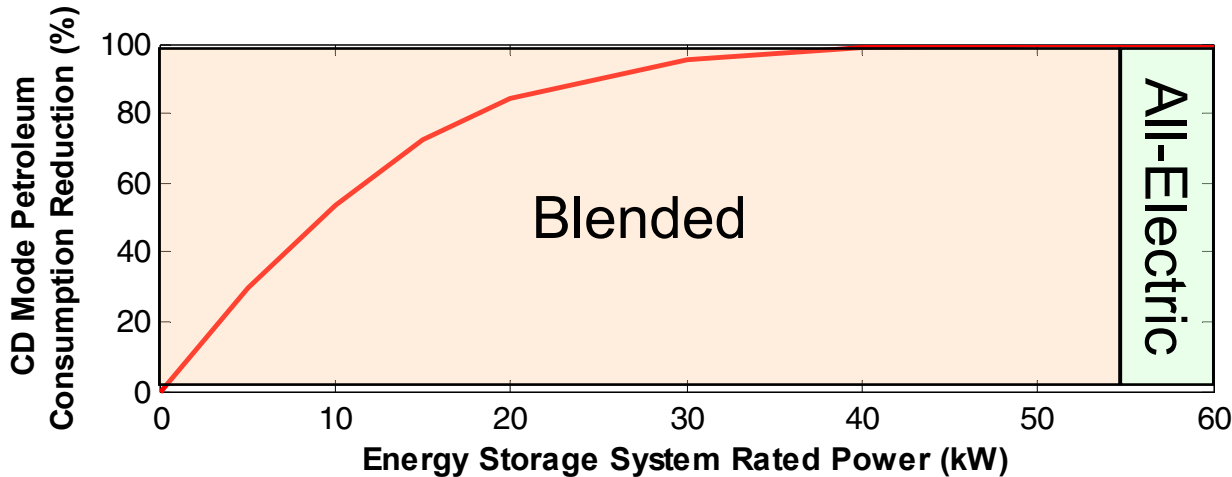
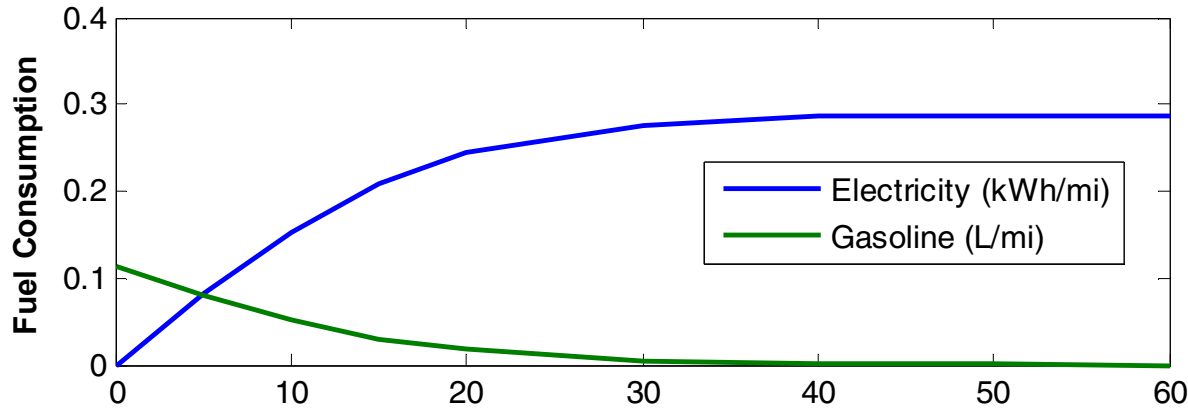


- Engine turns on when power exceeds battery power capability
- Engine only provides load that exceeds battery power capability

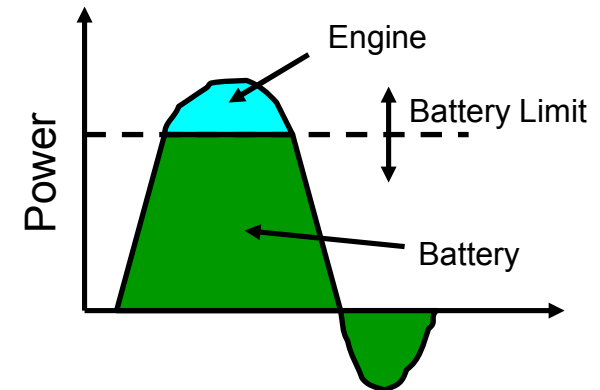


# Blended vs. AER Consumption Tradeoff

PHEV20 on LA92

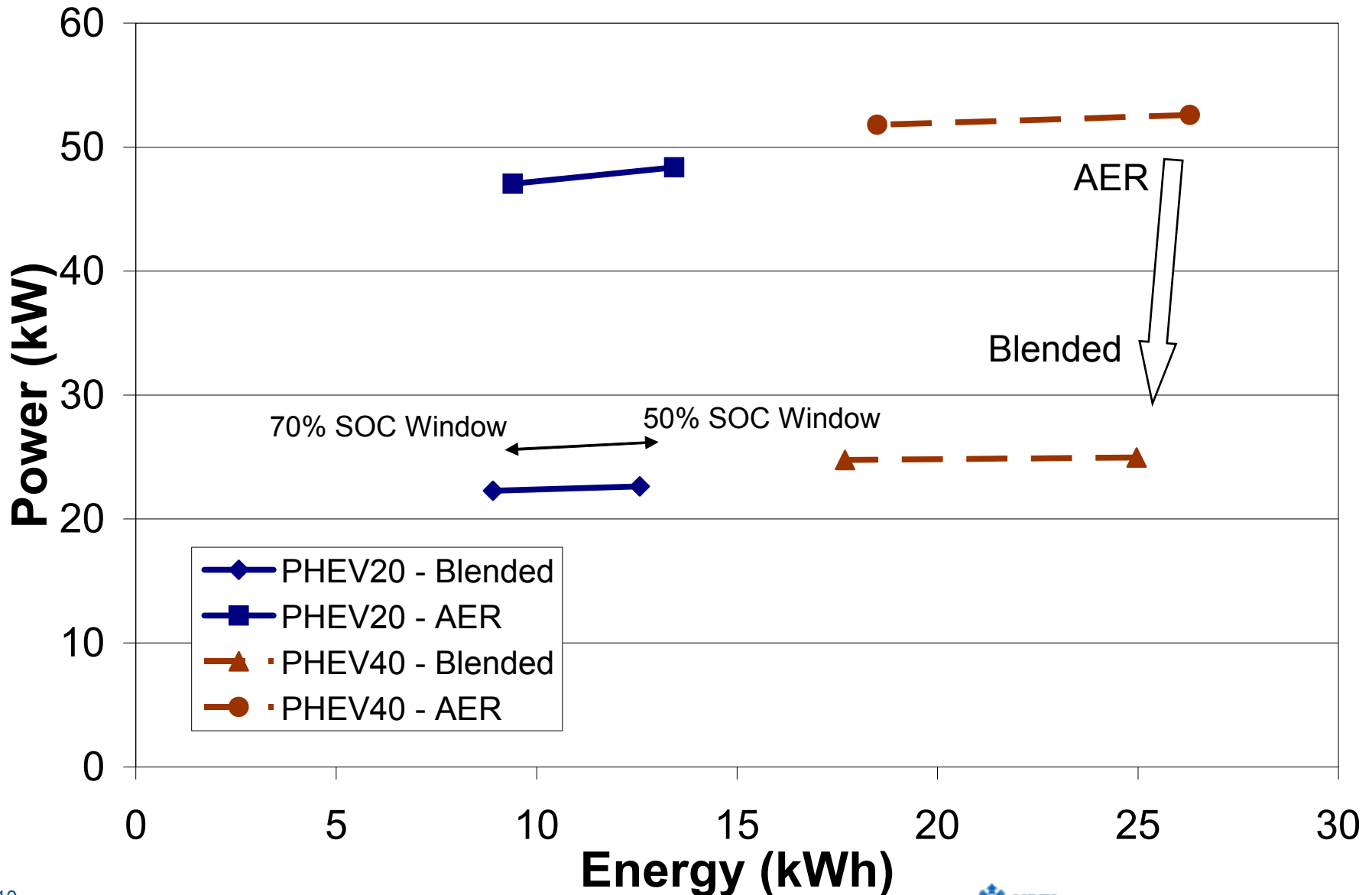


- Reducing ESS power should reduce cost, mass, volume
- 50% reduction in power still provides almost all of the fuel consumption benefit



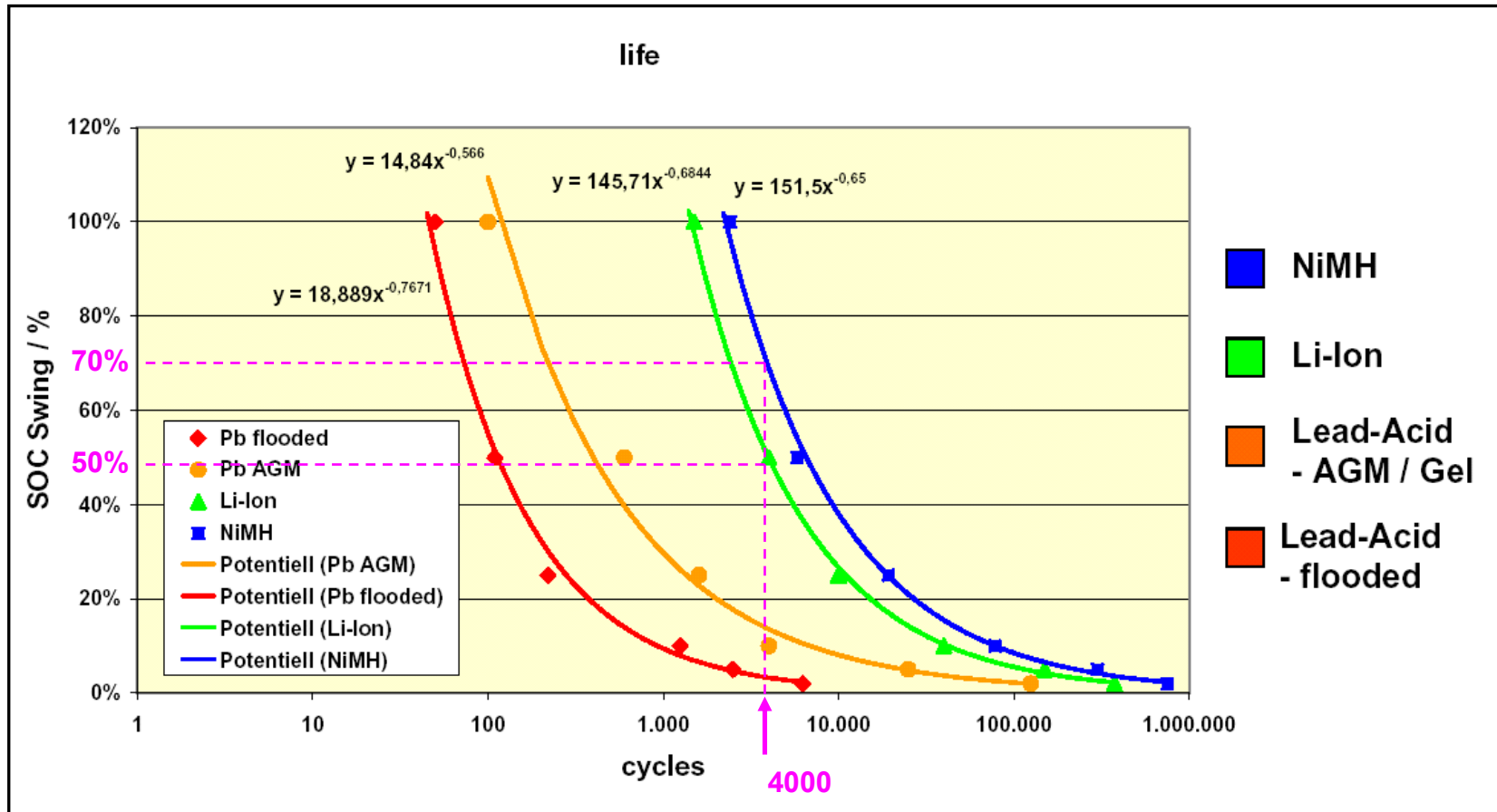
\* CD = Charge Depleting

# PHEV Battery Sizing Alternatives



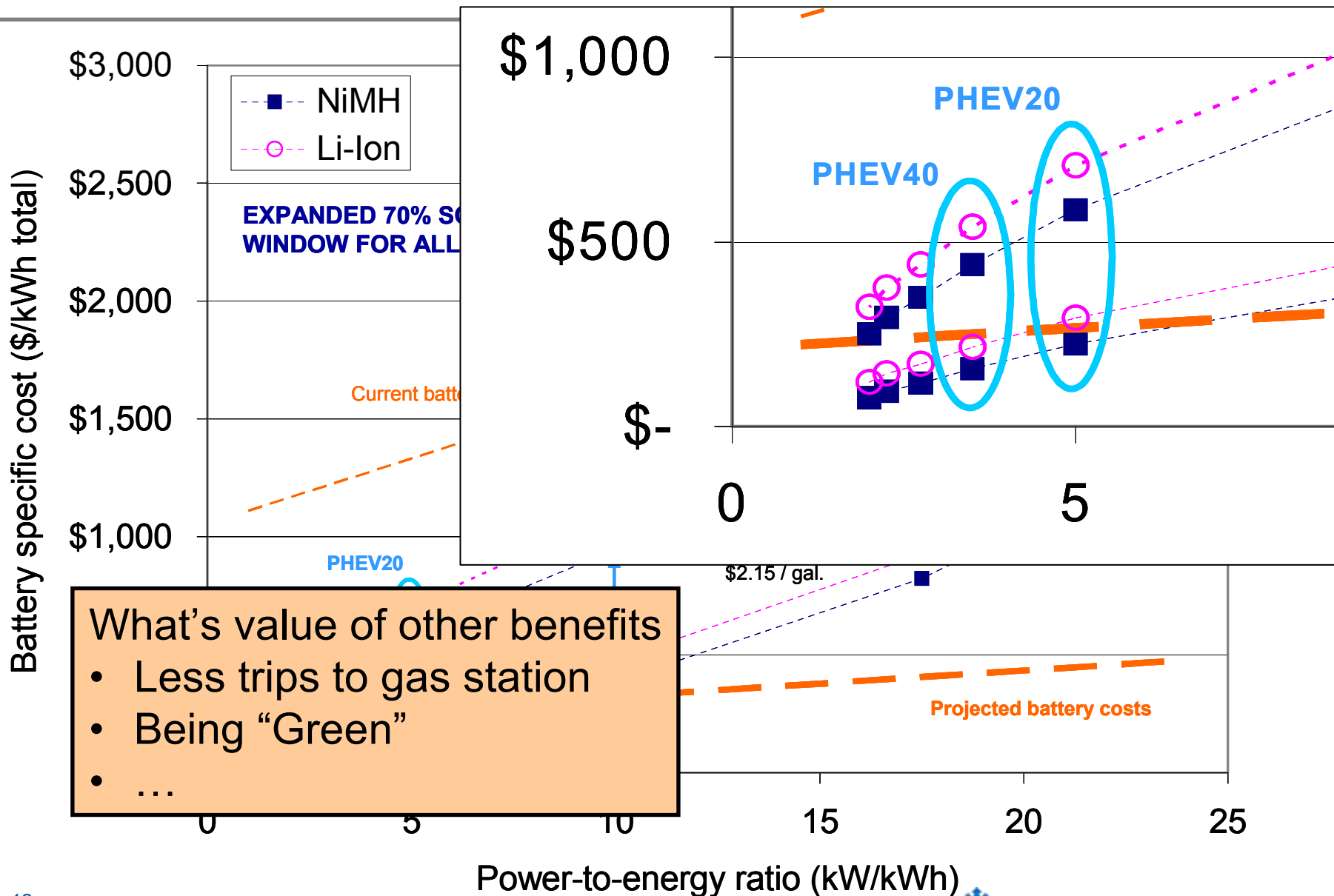
# Battery Life

- PHEV battery likely to deep-cycle each day driven: 15 yrs equates to 4000-5000 deep cycles
- Also need to consider combination of high and low frequency cycling



Data presented by Christian Rosenkranz (Johnson Controls) at EVS 20

# PHEV Battery Cost Requirements for 5 Year Payback



- Plug-in hybrid technology can reduce petroleum consumption beyond that of HEV technology
- The study highlighted some of the PHEV design options and associated tradeoffs
  - Expansion of the energy storage system usable state of charge window while maintaining life will be critical for reducing system cost and volume
  - A blended operating strategy as opposed to an all electric range focused strategy may provide some benefit in reducing cost and volume while maintaining consumption benefits
- The key remaining barriers to commercial PHEVs are battery life, packaging and cost